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NASA TECHNICAL TRANSLATION NASA TT F-14,013

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Translation of: "K voprosu o tsiklicheskoy polzuchesti i relaksatsii zharoprochnykh splavov", Problemy Prochnosti, Vol. 1, No. 5, 1969, pp. 34-38.

N72-12459 (NASA-TT-F-14013) CYCLIC CREEP AND RELAXATION OF HEAT RESISTANT ALLOYS L.B. Getsov (Scientific Translation Service) Nov. 1971 11 p CSCL 11F G3/17

Unclas 09318

(... OR AD NUMBER) (CATEGORY)

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 NOVEMBER 1971

CYCLIC CREEP AND RELAXATION OF HEAT RESISTANT ALLOYS

L. B. Getsov

ABSTRACT. Study of the cyclic creep and relaxation in a series of heat resistant alloys at high temperatures. It is shown that it is impossible to extend the calculations of the creep and relaxation characteristics obtained for a static load on those for a variable load.

At the present time, methods of designing parts for strength with consideration of redistribution of stress through creep, especially under conditions of repeated and alternating stress, have undergone considerable development. /34*

The majority of investigators [1-5] link the fracture of materials under conditions of low-cyclic fatigue at high temperatures to processes of cyclic creep and relaxation. In cyclic high-temperature tests with a given amplitude of deformation (fixed loading), depending on the asymmetry of the cycle, alternating or repeated relaxation is observed. In tests with a given stress amplitude (soft loading), each cycle involves cyclic creep with either fixed or alternating sign.

The characteristics of creep under constant stress have been investigated in considerable detail, but the features of the behavior of materials under cyclic stress have been insufficiently examined.

*Numbers in the margin indicate pagination in the original foreign text.

The purpose of the current study[1] is to investigate the behavior of various high-temperature materials under conditions of cyclic creep and relaxation at high temperatures.

To perform the tests involving cyclic creep, we rebuilt a type UIM-5 loading apparatus [6] by adding a system of cyclic loading controlled by a special time-delay relay. The cyclic creep under conditions of elongation-compression were studied on a type UMP-1 apparatus [7] constructed on the basis of an IP-4M machine. By using a unit for automatically reversing the load and attachments which prevented loss of stability by the sample, it was possible to perform tests of cyclic creep with any given asymmetry of the cycle. Tests of repeated relaxation were performed on the 5IM machine [8]. To ensure an unloading rate corresponding to the relaxation rate at high stresses, measures were employed which made it possible to attain an unloading rate of 2.9 $kgf/mm^2 \cdot sec$. In the case of tests for creep and relaxation, samples were used whose working area measured 7 mm in diameter and whose lengths were 70 and 100 mm, respectively.

The tests for repeated relaxation were performed on perlitic steel (EI415) at 550° C, on 12% chrome steel EI802 (12K12VNMF) at 500 and 550° C, and on nickel-based alloys EI607A, EI765, EI826 and EI827 at 600-900° C.

At these temperatures, all of the materials investigated were structurally stable. The number of cycles was 5 to 7, with the relaxation time on each occasion being one hour. The stressing of the sample was performed after it was unloaded.

In a manner similar to that which was used in [10], in order to describe the nature of the cyclic instability of material in a plastic area, we can use the following division of materials in the case of cyclic stress under

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(1) The experimental part of the work was performed jointly with N. S. Lokalova and E. V. Rytvinskaya.

creep conditions: the materials were either cyclically capable of being softened, could be hardened, or were stable. As a rule, however, the materials could not be assigned to one of these categories over a wide range of temperatures and lifetimes.

In fact, repeated relaxation (Figure 1 and Table 1) revealed phenomena in which the material initially seemed to be capable of cyclic hardening, then capable of cyclic softening (EI765, 700° C). Under alternating creep, as we will show later on, there was initial hardening followed by stability.

An analysis of the results obtained for tests involving repeated relaxation (see Table 1 and Figure 1) shows that cyclic stability of material depends on temperature: at temperatures up to 700° C, nickel-based alloys are capable of being cyclically hardened, while at temperatures /35
of 750° C or more they are capable of being cyclically softened. In the case of brief relaxation, EI826 alloy softens somewhat at 750° C, while it becomes harder in longer tests. In tests involving repeated relaxation of steels EI415 and EI802 at temperatures of 500-550° C, these steels proved to be capable of cyclic hardening. In some cases, the nature of the instability of the materials under conditions of cyclic relaxation (hardening, softening or stability) is independent of the magnitude of the initial stress.

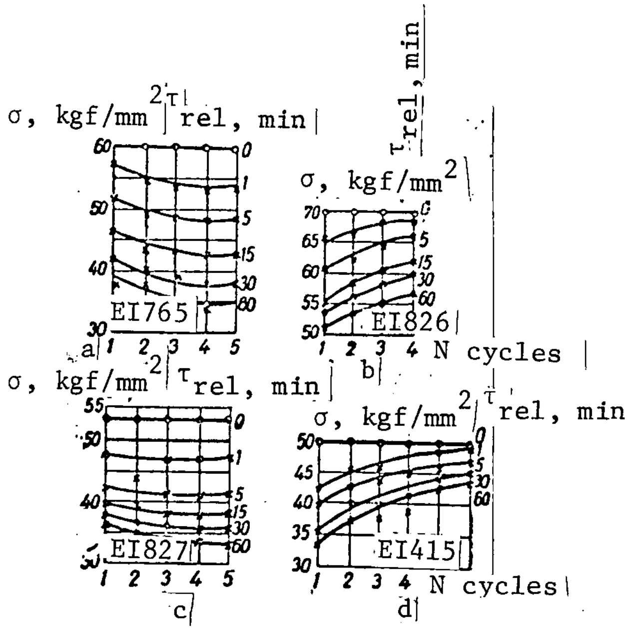

Figure 1. Graphic representation of the test results involving repeated relaxation of high-temperature alloys:

a - σ_0 = 60 kgf/mm^2 (750° C);

b - σ_0 = 70 kgf/mm^2 (700° C);

c - σ_0 = 53 kgf/mm^2 (800° C);

d - σ_0 = 50 kgf/mm^2 (550° C).

TABLE 1

Material	T, °C	σ, kgf/mm^2	σ/σ_y	Nature of the Dependence of $\lvert\Delta\sigma\rvert$ on the Number of Cycles
EI415	550	50	0.81	Cyclic Hardening
EI802	500	50	1.0	" "
	550	45	0.98	" "
EI607A	650	50	1.35	" "
	700	75	1.39	Slight Cyclic Hardening
EI765	650	80	1.11	Cyclic Hardening
	700	75	1.04	Slight hardening with short relaxation time; slight softening with long relaxation time.
	750	65	1.10	Slight cyclic softening
	750	55	0.93	Cyclic softening
EI826	700	70	1.2	Cyclic hardening
	750	65	1.14	Insignificant cyclic hardening at long relaxation times.
	800	55	1.08	Cyclic stability
	800	40	0.79	Cyclic stability at short relaxation times, insignificant hardening at long relaxation times.
EI827	600	80	1.31	Cyclic hardening
	700	70	1.17	" "
	750	65	1.25	Insignificant cyclic softening
	800	55	1.25	Ditto
	900	40	1.3	Cyclic stability

Tests for creep under cyclic stress ($\sigma_{max} = \sigma$; $\sigma_{min} = 0$) were performed under conditions of a square-wave cycle with frequencies of 1/48, 1/4, 1 and 12 cycles per hour. The results of the tests with EI607A alloy at 700° C are shown in Table 2.

TABLE 2

Test cycle, hours		τ_p (under stress), hours	δ_p, %	ψ_p, %	N, cycles	$v_{min} 10^{-4}$, %/hour
under stress	without stress					
Constant	-	1299	4.52	10.3	1	3
24	24	879	2.58	6.43	36.5	3.7
2	2	1626	1.9	5.95	812.5	1.3
0.5	0.5	908	1.83	-	1816	4.4
0.04	0.04	1650	2.07	20.1	32,600	1.6

Note: $\sigma = 27$ kg/mm^2.

The cyclic creep curves have three sections, like ordinary curves at constant stress. The data presented in Table 2 indicate that in the case of tests of EI607A alloy at 700° C with different stress frequencies, the values for the time until rupture and the creep rates are within the limits of scatter of the results of tests for long-term hardness. In the case of prolonged disruption of the characteristic of plasticity δ_p and ψ_p, there is no regular change involving the increase in the number of cycles until rupture. In tests on austenitic chrome-nickel-manganese steel EI481 at 600 and 650° C, a definite relationship between the time until rupture and the creep rate and the frequency of cyclic stress was found (Table 3). In tests on EI481 steel under cyclic creep conditions and 600° C, long-term plasticity and time until rupture r decrease, while at 650° C they increase with an increase in the stress frequency. /36

TABLE 3

T, °C	σ, kgf/mm^2	Test cycles, hours		r (under stress), hours	δ_p, %	ψ_p, %	$v_{min}10^{-4}$, %/hour
		Under stress	Without stress				
600	40	Constant	-	2609	1.18	2.71	-
		24	24	2058	-	-	-
		0.5	0.5	1430	0.68	0.48	-
650	32	Constant	-	734	1.16	2.0	6.2
		24	24	892	0.8	3.0	3.1
		0.5	0.5	1603	3.35	8.3	3.6
		0.04	0.04	2320	-	-	3.7

Tests for cyclic creep with alternating stress were performed on EI765 and EI826 alloys at 750 and 800° C, respectively. At these temperatures, these materials are structurally stable and, as we showed earlier, soften cyclically under conditions of repeated relaxation.

In the tests, the period of the cycles was varied from 25 minutes to 48 hours. Figure 2 shows a graph representing the change in stress for a cycle with a period of 25 minutes. For cyclic tests with a duration of 8 to 48 hours at $\sigma = 0$, the holding time as well as the unloading and loading time can be disregarded. In addition, with $\delta = \delta_{max}$ the time of loading and unloading can lead to the holding time of the sample under stress by calculations using the formula $t_h = t/m+1$, where m is the slope of the curve of long-term hardness. This formula has been developed for a triangular cycle, on the basis of the principle of additive damage. With t = 45 seconds and m = 9,

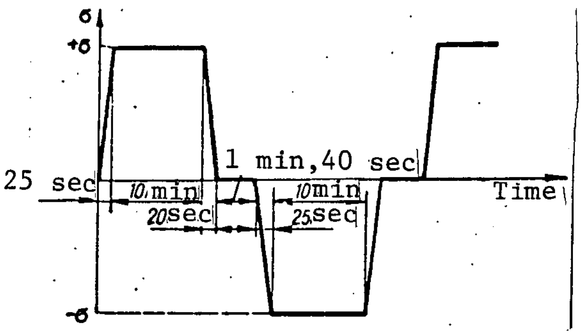

Figure 2. Test conditions for elongation-compression.

we will have t_h = 4.5 seconds, so that this time can be disregarded in comparison to the time under stress in a cycle of ten minutes - ten minutes.

An analysis of the experimental data presented in Table 4 and in Figures 3 and 4 indicates that, as the number of cycles increases, the creep of alloys EI765 and EI826 at 750-800° under conditions of cyclic elongation and compression increases /37 significantly (by 1.5 - 4 times). However, for a cycle period of 28 hours, the curves remain at a constant level, beginning with a third cycle, and last for about 15 cycles for a cycle period of 25 minutes.

In tests with a cycle period of 25 minutes, deformation per cycle was less than in tests with a cycle period of 8 to 48 hours.

Hence, the rate of stabilization of the curves of alternating creep clearly depends on the magnitude of deformation developed per cycle and the frequency of change of stress.

In all the tests, creep during compression was somewhat less (< 20%) than creep in experiments involving elongation. Similar behavior of creep during compression - elongation was observed in EI347 austenitic steel [9]. It was found that an elastic aftereffect has a certain influence on the characteristics of creep following a change of sign, but this influence is less than the influence produced by the difference in creep under elongation and compression.

If we compare the time-until-rupture results of the tests with alternating stress (τ_σ) with the results of tests under constant stress (τ_p), we can see that the ratio τ_σ/τ_p is more than 2.15, 1.43 and 0.55, respectively, for samples Nos. 2, 3 and 4 (see Table 4).

TABLE 4

No. of Samples	Material	T, °C	σ, kgf/mm^2	Period of cycle	Established creep per cycle ε_n, %		N, cycles	ψ, %	τ, hours^{-1}	τ_σ, r^{-2}
					Elongation	Compression				
1	EI765	750	25	48 hours	0.6	0.5	3	-	(144)	(144)
2			30	48 hours	0.65	0.5	10	-	(480)	(480)
3			40	25 minutes	0.11	0.07	127	4.2	53	42.4
4	EI826	800	30	25 minutes	0.24	0.18	178	3	74	59.4
5			30	8 hours	0.430	0.376	3	-	(24)	(24)

Note: 1. The time values for the tests of the samples which did not fracture are shown in parentheses.

2. τ_σ - time under stress.

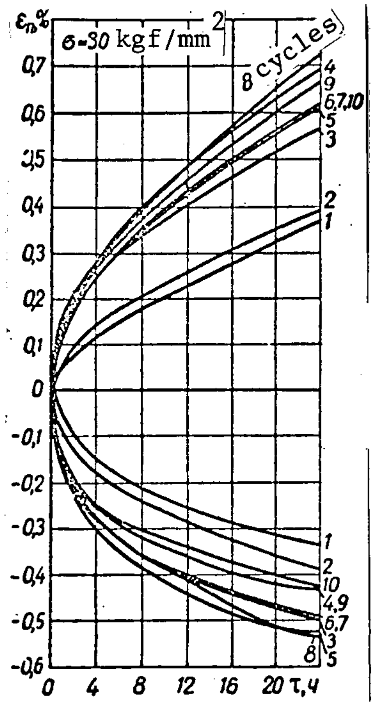

Figure 3. Creep curves under conditions of cyclic elongation-compression for alloy EI765 at 750° C.

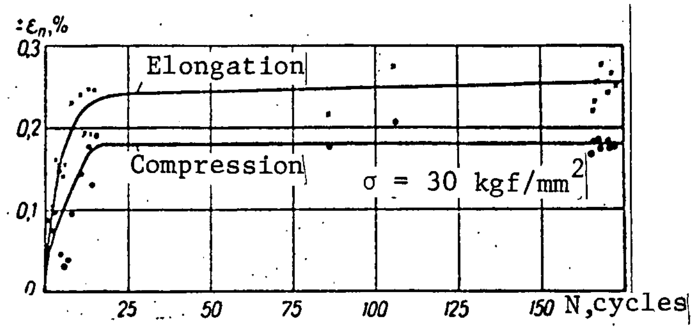

Figure 4. Creep of EI826 alloy at 800° C per half cycle in tests according to the following system: ten minutes elongation, ten minutes compression.

Investigation of the microstructure of ruptured samples (Figure 5) indicates a slightly different nature of the fracture. A sample made of EI765 alloy has a mixed type of fracture, with predominance of intergranular fracture, but in the fracture zone and on its surface (in contrast to samples tested under constant stress) there are no pores or cracks, with the exception of those that develop over the entire cross section of the intergranular crack. A sample made of EI826 alloy has a mixed type of fracture; intragranular cracks are found on its surface.

Hence, an intragranular type of fracture is observed in the case of reduced time until rupture with alternating load on samples in comparison with τ_p at a constant load, while a mixed type of fracture is found with an increase in the time until rupture.

The test results obtained indicate that using creep curves, in the case of static loads, for calculating the redistribution of stresses and the

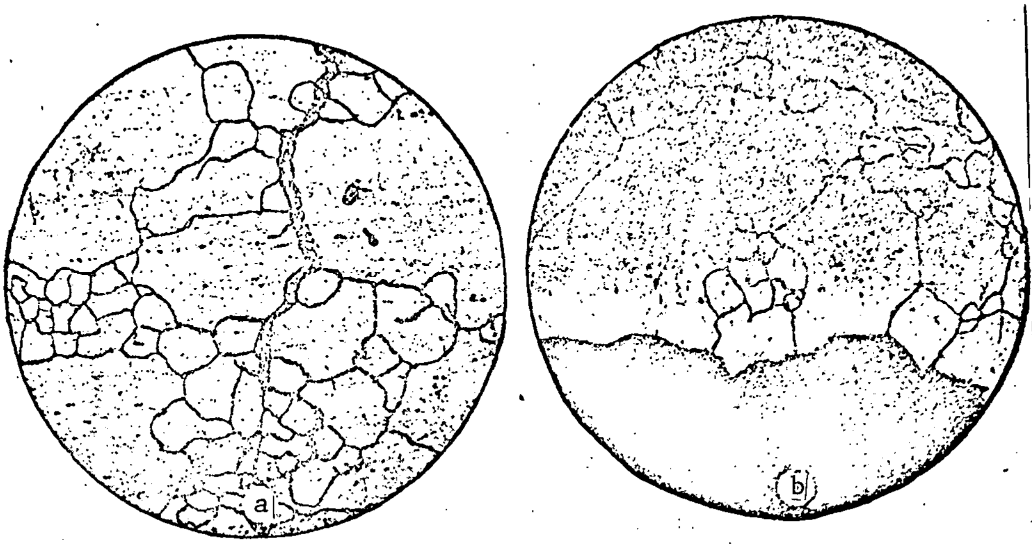

Figure 5. Microstructure of alloys EI765 (a) and EI826 (b) following tests involving alternating creep.

accumulation of creep under conditions of cyclic loads may lead to considerable errors, especially in the case of alternating loads. It should also be pointed out that, in the case of cyclically unstable materials, a change in the plasticity reserve of the material may develop in cyclically unstable materials /38 under conditions of cyclic creep in conjunction with a change in deformation per cycle. This in turn can cause changes in its lifetime.

REFERENCES

1. Serensen, S. V. Questions of Carrying Capacity with a Small Number of Loading Cycles. Doklad na III soveshchanii po mekhanicheskim voprosam ustalosti (Report to the III Conference on Mechanical Problems of Fatigue), 1966.

2. Kostyuk, A. G., A. D. Trukhniy and L. B. Getsov, Teploenergetika, No. 1, 1965.

3. Raraty, L. E. and R. W. Suhr. J. Inst. Metals, No. 8, 1966.

4. Taira, S. High Temperature and Materials. Pergamon Press, 1964.

5. Edmunds, H. G. and D. J. White. J. Mech. Engng. Sci., No. 3, 1966.

6. Getsov, L. B. and B. F. Plyasynkov. Zavodskaya Laboratoriya, No. 7, 1960.

7. Getsov, L. B. A Method for Studying High-Temperature Creep with Variable Compression-Elongation. Zavodskaya laboratoriya, No. 11, 1968.

8. Getsov, L. B. Zavodskaya laboratoriya, No. 11, 1963.

9. Taira, S. and R. Kotarazawa. Proc. 6th Japan Congr. Test. Mater, Kyoto, 1962, 1963.

10. Serensen, S. V. and R. M. Shneyderovich. Collection: Soprotivleniye deformirovaniyu i razrusheniyu pri malom chisle tsiklov nagruzheniya (Resistance to Deformation and Rupture with a Small Number of Loading Cycles). Moscow, Nauka Press, 1967.

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